IB/2004/051266

US030248

PA 1079929

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

October 16, 2003

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

APPLICATION NUMBER: *60/489,686*
FILING DATE: *July 24, 2003*

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

L. Edelen

L. EDELEN
Certifying Officer

PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53(b)(2).

Docket Number		Type a plus sign (+) inside this box ☐	+
US030248			

INVENTOR(s)/ APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
SHANKAR	SAI		TARRYTOWN, NY

TITLE OF THE INVENTION (280 characters max)

AN EFFICIENT ADMISSION CONTROL ALGORITHM FOR IEEE 802.11e

CORRESPONDENCE ADDRESS

Corporate Patent Counsel
U.S. Philips Corporation
P.O. BOX 3001
Briarcliff Manor, NY 10510

STATE	New York	ZIP CODE	10591	COUNTRY	U.S.A.

ENCLOSED APPLICATION PARTS (check all that apply)

X	Specification	Number of Pages	17	☐	Small Entity Statement
☐	Drawing(s)	Number of Sheets		☐	Other (specify)

METHOD OF PAYMENT (check one)

		PROVISIONAL FILING FEE AMOUNT ($)	160.00
☐	A check or money order is enclosed to cover the Provisional filing fees		
X	The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 14-1270		

S:\BI\US030248-PROVIDUMP.DOC

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

- [x] No

- [ ] Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE: ______________________ Date: JULY 23, 2003

TYPED or PRINTED NAME: STEVEN R. BIREN

REGISTRATION NO.: 26,531

- [ ] Additional inventors are being named on separately numbered sheets attached hereto

CERTIFICATE OF EXPRESS MAILING

Express Mail Mailing Label No. EV 312 068476

Date of Deposit JULY 23, 2003

I hereby certify that this paper and/or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 C.F.R. 1.10 on the date indicated above and is addressed to the Commissioner of Patents and Trademarks, Washington, D.C. 20231.

Edna Chapa — Edna Chapa

Typed Name — Signature

S:\BI\US030248-PROVIDUMP.DOC

PATENT APPLICATION SERIAL NO. ____________________

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

07/28/2003 GGEBREGI 00000109 141270 60489686
01 FC:1005 160.00 DA

PTO-1556
(5/87)

*U.S. Government Printing Office: 2002 — 489-267/69033

Efficient Admission Control Algorithm for IEEE 802.11e

Sai Shankar N
Philips Research USA
Briarcliff Manor, New York, USA
E-mail: sai.shankar@philips.com

Summary

This note provides an efficient admission control algorithm for IEEE 802.11e.

History

Revision	Editor	Date	Change History
0.4	szn and ams	10/31/2002	Fourth draft and revision sent to Atul
0.3	szn and jdp	10/25/2002	Third draft
0.2	szn and jdp	10/23/2002	Second draft
0.1	szn	10/14/2002	First draft

1 Introduction

QoS and multimedia support are critical to wireless home networks where voice, video and audio will be delivered across multiple networked home electronic devices. Broadband service providers view QoS and multimedia-capable home networks as an essential ingredient to offering residential customers video on demand, audio on demand, voice over IP and high-speed Internet access. QoS is also a critical element for consumer electronic companies looking to offer home wireless networking devices. Currently IEEE 802.11e is being considered by the consumer electronic as well as the data communication companies as "the" solution to offer QoS. The IEEE 802.11e draft version 3.3 (802.11e/D3.3), approved in September 2002, forms the core of what will eventually become an approved standard in the future. The draft provides protocol for QoS support but not the algorithms that are required along with the protocol to guarantee QoS. In order to make IEEE 802.11e support diverse QoS requirements of diverse markets, we need an efficient admission control algorithm as well as a good scheduling algorithm. Although admission control and scheduling are inseperable, we assume that there is a optimal scheduling algorithm and go about in designing the admission control algorithm. Admission control algorithm decides to admit QoS streams based on the scheduling algorithm. This document is about admission control algorithm and scheduling is not within the scope of this document.

2 Overview of HCF

Hybrid Coordination Function (HCF) is a coordination function that combines, and enhances, aspects of the contention-based and polling-based access methods, defined in IEEE 802.11-99 standard, to provide QoS stations (QoS STAs) with prioritized and parameterized QoS access to the wireless medium (WM), while continuing to support non-QoS STAs for best-effort

transfer. The HCF is upwardly compatible with the distributed coordination function (DCF) and may optionally contain the point coordination function (PCF). It supports a uniform set of frame formats and exchange sequences that QoS stations (QSTAs) may use during both the contention period (CP) and the contention free period (CFP). [1]

The HCF includes two different medium access mechanisms, namely, Enhanced Distributed Coordination Function (EDCF)[2] and polling-based channel access. The HCF is implemented at all QSTAs. As it is clear from the fact that the HCF has two access mechanisms, the HCF combines the functions of PCF and DCF, and does some enhancements to access the wireless medium. These enhancements allow for a uniform set of frame exchanges during both CP and CFP.

The HCF manages the allocation of Wireless Medium (WM) data transfer using a hybrid coordinator (HC)[3] that has higher medium access priority than the QoS STAs (QSTA or WSTAs). The HC uses this higher access priority to allocate Transmission Opportunities (TXOPs) to QSTAs. The HC is a type of point coordinator (PC) but differs from it in two important manners.

1) The HCF frame exchanges takes place among all QSTAs associated in the QBSS and happens during both CP as well as CFP. In case of CP the HCF access is limited by the CAPlimit specified by a MIB variable.
2) The QoS (+)CF-Polls grant a TXOP with the duration specified in the QoS (+)CF-Poll frame. QSTAs can transmit multiple frames subject to their TXOP limit.

The HC performs the delivery of queued broadcast, multicast or unicast frames following Delivery Traffic Indication Map (DTIM) beacons in a Contention Free Period (CFP). The length of the CFP is limited by the dot11CFPMaxDuration. When the HC needs to access the WM to start a CFP or contention free burst (CFB), the HC shall sense the WM to be idle for one PIFS period and then transmit any permitted frame with the duration value set. The HC need not perform random backoff.

3 Admission Control in IEEE 802.11e

3.1 Reasons for Admission Control

Providing quality of service (QoS) guarantees in Wireless LANs is an inherently challenging task. The time varying nature of the channel and mobility of users imposes additional constraints in guaranteeing the QoS requirements of the applications as compared to their wired counterparts. The mobility of user is important as it introduces location dependent errors. Based on the applications that are available today and the projection of futuristic applications that will be

[1] One contention-based channel access mechanism of the HCF is referred to as the "EDCF." It is closely related to the DCF channel access mechanism being viewed as an "Enhanced" version of that mechanism.

[2] Even if the EDCF includes the term "coordination function" in its name, it should be clarified that the EDCF is not a coordination function, but a channel access mechanism of the HCF, based on a carrier sense multiple access with collision avoidance (CSMA/CA), which is the access mechanism used in the DCF of IEEE 802.11-1999.

[3] A type of point coordinator - defined as part of the QoS facility - that implements the frame exchange sequences and MSDU handling rules defined by the hybrid coordination function. The HC operates during both the CP and CFP. The HC performs bandwidth management including the allocation of TXOPs to QSTAs and the initiation of controlled contention intervals. An HC is collocated with a QAP.

available in few years, there arises a fundamental question in designing a QoS solution for WLAN: How much traffic can the wireless network handle if prescribed QoS for each traffic is to be maintained while the network utilization, that is, throughput, is to be maximized? Alternatively, one can think of what wireless resources are required to support the QoS of a traffic stream? An Admission Control Unit (ACU) precisely does this. Given the channel capacity, how many connections can the ACU admit? We shall discuss different admission control policies based on the traffic occupancy in the wireless medium. The traffic occupancy is derived from the TSPEC parameters supplied by the higher layer entity to the MAC layer.

The QoS guarantees of an application depends on admission control algorithm for wireless LANs, or careful resource allocation based on time varying nature of the channel and location dependent errors. Furthermore, many of the admission control schemes today do not take into consideration the time varying nature of the channel or the location dependent errors or does not consider multi-rate transmission that is very common in IEEE 802.11e. The challenge is to design an efficient admission control algorithm under the above constraints.

In this note, we explore this notion of QoS provisioning by proposing a dynamic admission control scheme that uses the dynamically estimated channel error probabilities and time varying channel capacity along with the QoS requirements of the traffic stream that are specified in the traffic specification (TSPEC) element of IEEE 802.11e Draft 3.3. ACU is a decision maker which decides whether the stream, either upstream or downstream or sidestream, can be admitted into the wireless system based on the channel and traffic characteristics. The channel conditions such as, channel rate and errors need to be estimated dynamically and this note will not concentrate on the estimation algorithms to determine the channel or link state and error rates. It is assumed that the link state and error rates are known apriori. Once a stream is admitted, control must be maintained at the entrance to the MAC to ensure that the traffic entering the network receives its negotiated QoS and does not adversely affect the other existing traffic. This is done by appropriately scheduling the different traffic streams and policing each stream to ensure that each stream abides by its traffic estimate. The scope of this note extends to traffic streams or parameterized traffic and the next section explains how the MAC layer identifies whether a frame belongs to parameterized QoS or prioritized QoS.

There are two types of QoS as specified in IEEE 802.11e draft 3.3. They are prioritized QoS and parameterized QoS. The way to differentiate traffic between prioritized or parameterized is by means of TID value. It is assumed that prioritized will use EDCF and parameterized will use polling based channel access. This assumption does not preclude the possibility of serving prioritized traffic using polling based channel access. This note discusses the admission control for parameterized traffic.

3.2 Admission Control

The objective here is quite simple: given an arriving stream with the TSPEC parameters specified by the Draft 3.3, can we admit the stream into the network or not? How is the ACU going to make the admission decision? What parameters must be used by the ACU to make the decision? These are some questions that are very important for the design of the ACU. We start with the admission control algorithm and then go on to explain on how to implement in the IEEE 802.11e MAC-SAP.

3.2.1 What are the inputs for the admission control?

The Draft 3.3 specifies Traffic Specification (TSPEC) element, which represents the characteristics of the application traffic that comes to the MAC. This information is partially filled by layers above MAC and some fields are filled by the MAC. The TSPEC element contains the set of parameters that define the characteristics and QoS expectations of a unidirectional traffic stream for use by the HC and WSTA(s) in support of parameterized QoS. The following fields are part of TSPEC element. For details regarding each field, the reader is referred to draft 3.3.

Octets: 1	1	2	2	2	4	4	4	4	4
Element ID (13)	Length (44)	TS Info	Nominal MSDU Size	Maximum MSDU Size	Minimum Service Interval	Maximum Service Interval	Inactivity Interval	Minimum Data Rate	Mean Data Rate

4	4	4	1	1
Maximum Data Rate	Minimum PHY Rate	Peak Data Rate	Delay Bound	Surplus Bandwidth Allowance

Figure 1 – Traffic Specification element format

Among the 12 important fields excluding the Element ID field, Length Field and TS Info Field, Minimum PHY Rate and Surplus Bandwidth Allowance are specified by the MAC. In the TS Info field, the ACK Policy, and direction are also set by the MAC.

The Traffic Specification allows a set of parameters more extensive than may be needed, or may be available, for any particular instance of parameterized QoS traffic. The fields are set to zero for any unspecified parameter values. The structure of the TS Info field is defined in Figure 2.

bits: 0	1	2-3	4	5-7	8-9	10-11	12-15
Traffic Type	reserved	TSInfo Ack Policy	reserved	User Priority	Direction	TSID	reserved

Figure 2 – TS Info field

The Traffic Type subfield is a single bit which is set to 1 for a continuous or periodic traffic pattern (e.g. isochronous traffic stream of MSDUs, with constant or variable sizes, that are originated at fixed rate), or is set to 0 for a non-continuous, aperiodic, or unspecified traffic pattern (e.g. asynchronous traffic stream of low-duty cycles).

The TSInfo Ack Policy sub-field is 2 bits in length and indicates whether MAC acknowledgement is required for MPDUs belonging to this TID, and the desired form of those acknowledgements. The encoding of the TSInfo Ack Policy field is shown in Table 1. If the TS Info Ack Policy is set to Group Acknowledgement, the HC shall assume, for TXOP scheduling, that the Immediate Group Ack policy is being used (see 9.10.5 of Draft 3.3).

Table 1 – TSInfo Ack Policy field encoding

Bit 2	Bit 3	Usage
0	0	Normal IEEE 802.11 acknowledgement. The addressed recipient returns an ACK or QoS (+)CF-Ack frame after a SIFS period, according to the procedures defined in 9.2.8, 9.3.3 and 9.10.3.
1	0	No acknowledgement The recipient(s) shall not acknowledge the transmission, and the sender treats the transmission as successful without regard for the actual result.
0	1	Alternate acknowledgement Reserved for future use, interpreted as normal IEEE 802.11 acknowledgement if received.
1	1	Group Acknowledgement A separate Group Ack set up mechanism described in 9.10.5 shall be used.

The User Priority subfield is 3 bits that indicates the actual priority value to be used for the transport of MSDUs belonging to this traffic stream in cases where relative prioritization is required.

The direction field defines the direction of Data carried by the traffic stream as defined in table 2.

Table 2 – Direction field encoding

Bit 8	Bit 9	Usage
0	0	Uplink (WSTA to HC)
1	0	Downlink (HC to WSTA)
0	1	Direct link (WSTA to WSTA)
1	1	Reserved

The TSID subfield is 4 bits in length and contains the TSID values in the format defined in 7.1.3.5.1. The combination of TSID and Direction identify the traffic stream, in the context of the WSTA, to which the traffic specification applies. The same TSID may be used for multiple traffic streams at different WSTA. A WSTA may use the TSID value for a downlink TSPEC and either an uplink or a direct link TSPEC at the same time. A WSTA shall not use the same TSID for both uplink and direct link TSPECs.

The Nominal MSDU Size field is used to specify the nominal size, in octets, of MSDUs belonging to the TS under this traffic specification and is defined in Figure 2a. If the Fixed subfield is set to 1, then the size of the MSDU is fixed and is indicated by the Size Subfield. If the Fixed subfield is set to 0, then the size of the MSDU might not be fixed and the Size indicates the nominal MSDU size. If both Fixed Subfield and Size are set to 0, then the nominal MSDU size is unspecified.

	B0 B14	B15
	Size	Fixed
Bits:	15	1

Figure 2a – Nominal MSDU Size Field

The Minimum Service Interval specifies the minimum interval, in units of microseconds, required by the TS in this TSPEC between the start of two successive TXOPs. If the Direction field is set to uplink or sidelink, the Minimum Service Interval is the minimum interval between the start of two successive QoS(+)CF-Polls.

The Maximum Service Interval specifies the maximum interval, in units of microseconds, required by the TS in this TSPEC between the start of two successive TXOPs. If the Direction field is set to uplink or sidelink, the Maximum Service Interval is the maximum interval between the start of two successive QoS(+)CF-Polls.

The Inactivity Interval field specifies the maximum amount of time in units of microseconds that may elapse without arrival or transfer of an MSDU belonging to the TS before this TS is deleted by the MAC entity at the HC. A value of 0 disables the Inactivity Interval, indicating that the TS is not to be deleted based on inactivity.

The Minimum Data Rate field specifies the lowest data rate, in units of bits per second, for transport of MSDUs belonging to this TS within the bounds under this traffic specification. The Minimum Data Rate does not include the MAC and PHY overheads incurred in transferring the MSDUs. This field is to be used to compute the bandwidth that the TS requires for transmission to meet minimum QoS requirements. A value of 0 indicates unspecified minimum data rate.

The Mean Data Rate field specifies the average data rate, in units of bits per second, for transport of MSDUs belonging to this TS within the bounds under this traffic specification. The Mean Data Rate corresponds to the rate of the second token bucket in a twin token bucket [B5][4] based traffic policer. The Mean Data Rate does not include the MAC and PHY overheads incurred in transferring the MSDUs. A value of 0 indicates unspecified mean data rate.

The Peak Data Rate field specifies the maximum allowable data rate in units of bits/second, for transfer of the MSDUs belonging to this TS within the bounds under this traffic specification. The Peak Data Rate corresponds to the rate of the first token bucket in a twin token bucket based traffic policer. If "p" is the peak rate in bit/s, then the maximum amount of data, belonging to this TS, arriving in any time interval [t1,t2], where $t1<t2$ and $t2-t1>1$ TU, must not exceed $p*(t2-t1)$ bits. A value of 0 indicates unspecified peak data rate.

The Maximum Burst Size field specifies the maximum data burst, in units of octets that arrive at the MAC SAP at the peak data rate for transport of MSDUs belonging to this TS within the bounds under this traffic specification. This corresponds to the second token bucket size in a twin token bucket based traffic policer. A value of 0 indicates that there are no bursts.

The Minimum PHY Rate field specifies the minimum PHY rate, in units of bits per second that is required for transport of the MSDUs belonging to the TS in this TSPEC. A value of 0 indicates unspecified minimum PHY rate. [5]

The Delay Bound field specifies the maximum amount of time in units of microseconds allowed to transport an MSDU belonging to the TS in this TSPEC, measured between the time

[4] The token bucket model provides standard terminology for describing the behavior of a traffic source. The TSPEC parameters defined above have an analogy to the parameters of the twin token bucket implementation. The analogy is used for clarification, but it is left to the implementer to use any traffic policer. The token bucket model is described in IETF RFC 2215[B5].

[5] This rate information is intended to ensure that the TSPEC parameter values resulting from an admission control negotiation are sufficient to provide the required throughput for the traffic stream. In a typical implementation, a TS is admitted only if the defined traffic volume can be accommodated at the specified rate within an amount of WM occupancy time that the admissions control entity is willing to allocate to this TS.

marking the arrival of the MSDU at the local MAC sublayer from the local MAC SAP and the time starting the successful transmission or retransmission of the MSDU to the destination. A value of 0 indicates unspecified delay bound.

The Surplus Bandwidth Allowance Factor field describes the excess allocation of time (and bandwidth) over and above the stated rates required to transport an MSDU belonging to the TS in this TSPEC. This field is a 2 octet field, which is represented as an unsigned binary number with an implicit binary point after the leftmost 3 bits. This field is included to account for retransmissions, and MAC and PHY overheads. It represents the ratio of over-the-air bandwidth to bandwidth of the transported MSDUs required for successful transmission to meet throughput and delay bounds under this TSPEC, when specified. As such, it must be greater than unity. If it is zero, it is unspecified.

The TS Priority, Minimum Data Rate, Mean Data Rate, Peak Data Rate, Maximum Burst Size, Minimum PHY Rate, and Delay Bound fields in a TSPEC express the QoS expectations requested by a WSTA, when these fields are specified with non-zero values. Unspecified parameters in these fields as indicated by a zero value indicate that the WSTA does not have requirements for these parameters.

3.2.2 Parameters used for admission control

Among the defined parameters, we use the subset of the parameters to design the efficient admission control. Those parameters are:

- Peak Data Rate (P)
- Mean Data Rate (ρ)
- Maximum Burst Size (σ)
- Delay (d)
- Nominal MSDU Size (L)
- Minimum PHY TX Rate (R) and
- Maximum MSDU Size (M=2304 bytes)

We also use the channel or link state to determine the additional percentage that needs to reserved for the bandwidth to cover the losses that may occur in the wireless medium. The Peak data rate, Mean data rate and the Maximum Burst Size are part of the twin token bucket parameters that are supplied by the higher layer entities to the MAC. In case the application does not provide such parameters the MAC needs to measure over small intervals and pass those parameters to the ACU co-located with the HC at QAP. *Philips has submitted a proposal on what parameters need to be mandatory so that inter-operability issue does not arise. We will first outline a detailed ACU and then go about using the same ACU to support efficient admission control using minimum set of parameters.*

4 Design of the Admission Control Unit

4.1 Concept of Dual Token Bucket

Stream connections that provide the above TSPEC parameters are monitored so as to comply with the above TSPEC parameters by the ACU. Policer does the job of monitoring the traffic stream and ensures that the admitted stream complies with the parameters it had set in the TSPEC element. If the stream is not complying with the TSPEC parameters the policer takes appropriate actions like discarding the frame or marking those frames as lower priority frames. The token bucket policer is associated with each traffic stream and it exactly does this job. This policer is situated at the entrance of the MAC. It takes into account the peak data rate, mean data rate and

maximum burst size parameters from the TSPEC specification and ensures that the actual arriving frames of the corresponding stream comply with the parameters it agreed upon. The figure 3 shows the dual token bucket policer.

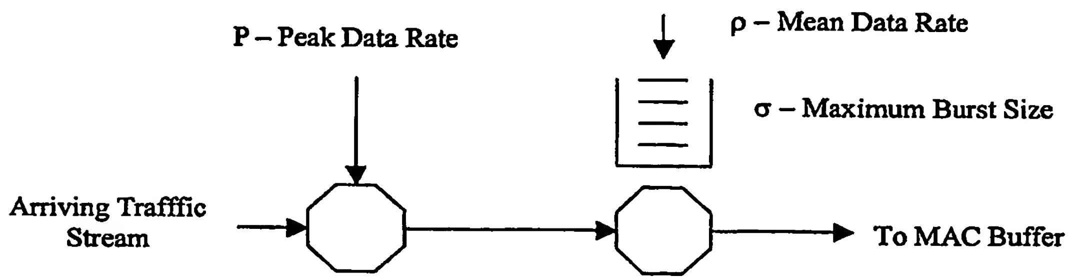


Figure 3 - Twin Token Bucket Policer

The dual token bucket is composed of two token buckets, with the first token bucket value is always set to 0 and the second one is set to the value equal to the maximum burst size. The tokens arrive at the first bucket, which has 0 bucket size, at the peak data rate and the tokens arrive at the second bucket at the mean data rate. If an incoming MSDU of size L of the stream arrives at the first token bucket, it needs to wait till the token arrives from the first generator. If it does not find a token at its time of arrival it needs to wait a maximum of L/P time units before the tokens are generated and is passed to the second token bucket policer. If there is atleast one token in the second token bucket, it is immediately sent to the MAC buffer or it needs to wait for the time L/ρ before it is sent to the MAC buffer. Now we derive the mathematical bounds on the arrival pattern of the streams that pass through the twin token bucket filter whose values is determined from the TSPEC parameters.

If one takes the first token bucket filter alone, it is easy to say that the stream can send a maximum of P*t bytes in time t. If one takes the second token bucket filter alone, in any time t, the amount of bytes that can be sent is σ+ρt. So combining the first and second token bucket filters as shown in the figure 3, we have the arrival process of a stream passing through its token bucket constrained by

$$A(t,t+\tau) = Min(P\tau, \sigma + \rho\tau) \tag{1.1}$$

where $A(t,t+\tau)$ is the cumulative number of arrivals in the time interval $(t,t+\tau)$. From Equation (1.1) we can construct the arrival rate curve which is drawn in the figure 4.

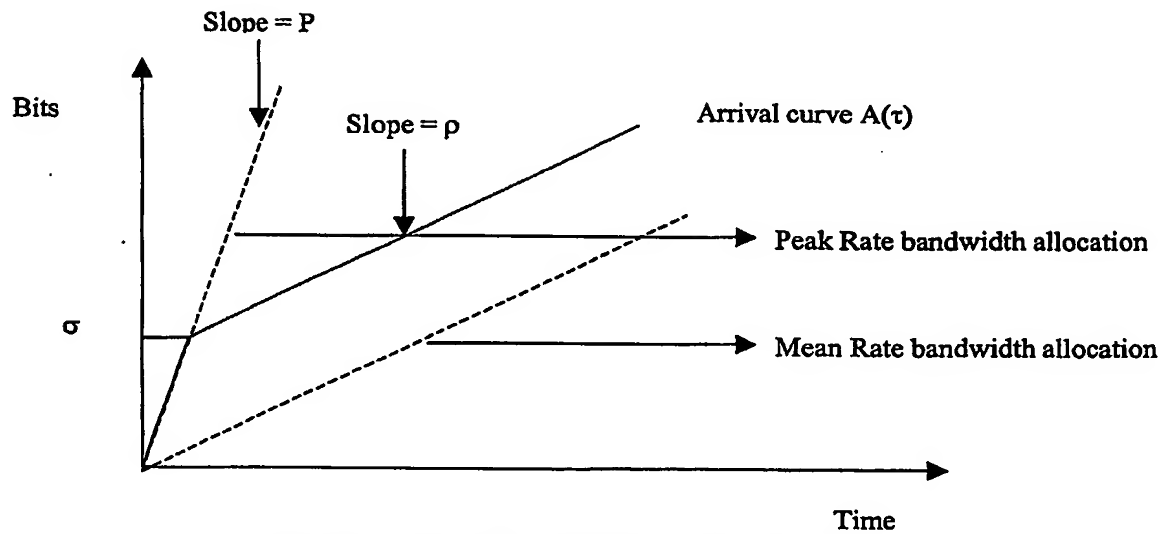


Figure 4 – Envelope or Arrival Curve Processes

The curve drawn above is also called as envelope process, which bounds the amount of traffic that arrives at the WSTA/QAP's MAC buffer in any given interval of time. As per Eqn.(1.1) we can say that the envelope process $A(\tau)$ exists such that

$$A(t, t+\tau) \leq A(\tau) \tag{1.2}$$

for any times t and τ.

4.2 Admission Control Design

4.2.1 Peak and Mean Data Rate allocation

From the curves indicated above, two admission control schemes arise immediately. One scheme is the bandwidth allocation based on **peak data rate** and the other based on the **mean data rate.** If the ACU were to allocate bandwidth to the stream using peak data rate information, it would result in admitting only few streams, as streams send at their peak data rate only for short durations. So this results in wasting the channel capacity (Channel throughput), but all the admitted streams are guaranteed absolute bandwidth. It is the lower bound on the number of streams that can be admitted. This is given by $\left\lfloor \frac{C}{P} \right\rfloor$. On the other hand if the ACU were to admit streams based on mean data rate, the ACU would pack more streams on the wireless channel resulting in loss of MSDUs, when streams send MSDUs at their peak data rate. But the mean data

rate allocation results in increased channel throughput. But this method of bandwidth allocation results in QoS degradation for all the streams. This is given by $\left\lfloor \frac{C}{\rho} \right\rfloor$.

So the goal of the ACU is to take into account the concept of **statistical multiplexing** of frames over the wireless channel. Statistical multiplexing concept states that not all streams send data at the peak data rate at the same time. So one can pack more streams than one would pack using the peak data rate allocation. The upper-bound on the maximum number of streams that can be admitted is when the streams are admitted using the mean data rate. But we try to find an optimal number between the peak and mean data rate such that we can pack more streams into the wireless channel and still guarantee the QoS requirements of all those streams admitted. This is accomplished by effective bandwidth or guaranteed rate. Now we ask the question on how to calculate this effective bandwidth (or Guaranteed rate) for a stream that comes with the TSPEC parameters?

4.2.2 Concept of Guaranteed Rate or Effective Bandwidth

Since each stream requires its delay QoS to be satisfied, we take the delay bound parameter into account to determine the effective bandwidth of the stream. We again refer to the figure 5 to calculate the effective bandwidth.

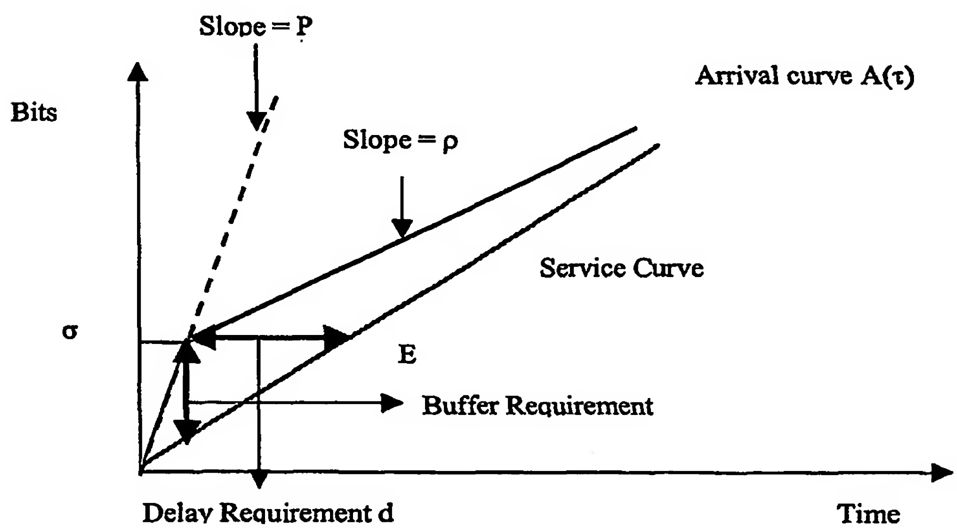


Figure 5 – Determination of Effective Bandwidth or Guaranteed Rate

In the figure 5 the dashed brown line represents the arrival of burst of size σ at the peak data rate. After sigma, as per equation (1.1) the slope of the curve changes to mean data rate represented by the dark black line. Along with the arrival rate parameters, we also have the delay parameter. Now at the point, σ, where the slope of the arrival rate curve changes from peak data rate to the mean data rate, we draw the straight red line, which is the delay budget allowed for that stream. Now construct a straight green line drawn from origin and passing through E. This line is the effective bandwidth or guaranteed rate line that guarantees the QoS as desired by the application that mentions the traffic specification parameters along with its QoS expectations. The vertical

blue line represents the buffer size needed for the application. Using the distance formula the length of the vertical blue line and hence the buffer for the stream is given by

$$b_i = \frac{P_i - g_i}{P_i - \rho_i}\sigma_i \tag{1.3}$$

where g_i is the guaranteed service rate for this session. Based on the buffer size, the last bit of the fully loaded buffer is going to suffer the maximum delay as that bit needs to wait for the entire buffer to be served. But from the curve the delay bound is constrained by d_i based on the guaranteed service rate g_i. We can express this by a simple equation as

$$\frac{b_i}{g_i} \le d_i \tag{1.4}$$

From Eqns. (1.3) and (1.4), we can make g_i the subject of the formula. This is found to be

$$g_i = \frac{P_i}{1 + d_i \dfrac{P_i - \rho_i}{\sigma_i}} \tag{1.5}$$

This rate g_i is called the guaranteed rate because this is the minimum rate that takes into all the parameters of the traffic for the stream and ensures that this bandwidth is required for satisfying the QoS parameters of the stream. The simple admission control decision for an arriving $(k+1)^{th}$ would be based on the following rule.

$$g_{k+1} + \sum_{i=1}^{k} g_i \le C \tag{1.6}$$

The above equation states that if the newly arriving stream with guaranteed rate g_{k+1} satisfies the equation (1.6) then the flow $(k+1)$ shall be admitted. But a natural question that arises is that if we pack the wireless channel capacity without including the channel error rate, will the system be able to guarantee the QoS requirements of the stream? The answer is "no" if the system is completely packed. Since for errored frames we need to have retransmissions, we need to some budget of the channel capacity allocated for retransmissions. Calculations that include the error rate is worked out in next subsection.

4.2.3 Inclusion of channel error rate

As we mentioned earlier, wireless channel is prone to errors because of interference from other sources as well as errors depending on their location from the QAP. How to estimate errors is not discussed in this deliverable. One simple way is to use the RSSI value from a received ACK or data frame and use that information to estimate the error probability of a MSDU. Let the error probability of the frame be given by p_e. This p_e can be estimated from the past history of the link condition to this WSTA or QAP or can be determined based on the admission control requests emanating from the WSTA. If the ACU is to consider this information is deciding to admit the stream the guaranteed rate given in equation (1.5) becomes

$$g_i = \frac{P_i}{[1 + d_i \dfrac{P_i - \rho_i}{\sigma_i}][1 - p_e]} \tag{1.7}$$

From the above equation it is easy to infer that when the packet error probability is 0, the guaranteed rate is same as equation (1.5), but becomes infinity if the packet error probability becomes 1 implying that we can't transport the stream with any finite bandwidth. The second question that arises is that if we pack the wireless channel capacity without including the channel overheads, will the system be able to guarantee the QoS requirements of the stream? The answer is "no" if the system is completely packed. This is because we get 54Mbps of raw channel capacity in case of IEEE 802.11a PHY without considering overheads like SIFS, PIFS and the time to send CF(+)QoS Poll etc. The next subsection outlines the way to include the overheads and use them in admission control process.

4.2.4 Time varying link capacity

We know that in the IEEE 802.11e environment different QSTAs can communicate to QAP using different PHY rates. For example, if the IEEE 802.11e QBSS is using an IEEE 802.11a physical layer, there are eight modes with which a QSTA can communicate to QAP and viceversa. This may based on the location of the QSTA from QAP. If different QSTAs communicate to QAP using different rates, how are we going to make a unified admission control algorithm? In sections 4.2.1 to 4.2.3 we assumed that the channel capacity is constant and all QSTAs communicate to the QAP at the same physical rate. The second reason is that the PHY rate at which the QSTA/QAP communicate with other QSTA can vary over time because of mobility. The PHY rate can increase or decrease. Increasing PHY rate poses no problem as it will give the ACU the benefit of admitting more streams. The problem arises when the PHY rate drops and the wireless channel is nearly full. To include this time varying link capacity, we introduce the concept of transmission burstiness and is represented by δ. The transmission burstiness is the amount of channel capacity that will fall from the original channel capacity. If C is the original channel capacity, in any time t, the maximum amount of bits that can be on the wireless medium is $C\times t$. But because of interference and mobility, the channel capacity may drop by a factor δ. So in any time t the lower bound on the channel capacity available to that stream is $C\times t-\delta$. Now the admission control equation (1.7) changes as

$$g_i = \frac{P_i}{[1+d_i\dfrac{P_i-\rho_i}{\sigma_i+\delta_i}][1-p_e]} \tag{1.8}$$

This δ is obtained by the differnce of observed PHY rate at which the stream is transmitting currently and the minimum TX rate.

The second question that arises is that if we pack the wireless channel capacity without including the channel overheads, will the system be able to guarantee the QoS requirements of the stream? The answer is "no" if the system is completely packed. This is because we get 54Mbps of raw channel capacity in case of IEEE 802.11a PHY without considering overheads like SIFS, PIFS and the time to send CF(+)QoS Poll etc. The next subsection outlines the way to include the overheads and use them in admission control process.

4.2.5 Inclusion of Overheads

If we have to include these overheads we need to know the nominal MSDU size to compute the overheads that are added to each frame in terms of header overheads as well as the IFS times overheads. For this stream i, let the nominal MSDU size be L_i. For each frame there is an overhead in time based on the ACK policy, IFS time, PLCPPreamble, MAC and PHY layer headers and polling overhead (only in case of upstream or sidestream). The scheduling policy

also determines the polling overheads as different scheduling policies determine how many time one needs to poll a WSTA in the service interval denoted as SI. Let us assume that we know the scheduler and based on the scheduler we can easily derive the overhead per frame as O_i. So the number of MSDUs per service interval is given by

$$N_i = \left\lceil \frac{g_i * SI}{L_i} \right\rceil \tag{1.9}$$

Now the modified guaranteed that is required for this connection including overheads is given by

$$g_i^{'} = \frac{N_i(L_i + O_i)}{SI} \tag{1.10}$$

So the new admission control policy is given by the following equation.

$$g_{i+1}^{'} + \sum_{k=1}^{i} g_k^{'} \leq C \tag{1.11}$$

$g_{i+1}^{'}$ is the guaranteed rate or effective bandwidth including the overheads.

4.2.6 Conversion to Rate Parameters to Time

In-order to incorporate the multi-rate support, we use the concept of air-time. In this algorithm, we convert the rate based requirements of the stream into corresponding air-time based on the Minimum PHY TX Rate parameter. During the admission control negotiation, the ACU and the QSTA/QAP negotiate this parameter as to what is the Minimum PHY TX Rate that a QSTA and QAP/QSTA shall communicate. The actual PHY Rate can be more than the Minimum PHY Rate. If the rate of the source station (either QAP or QSTA) drops below the value of Minimum PHY TX Rate the stream is considered violating its QoS requirements and may be dropped by the ACU depending on the channel conditions. So the sufficient condition for the Minimum PHY TX Rate is

$$R_i \geq g_i^{'} \tag{1.12}$$

If the guaranteed rate for the HDTV stream including the overheads is 30 Mbps, the ACU may set the Minimum PHY Rate as 48 Mbps based on channel conditions and number of streams that are already admitted and how the channel is packed. As assumed earlier it is assumed that the scheduling scheme is known. Based on the prior knowledge of the scheduling scheme the ACU and the scheduler interact to generate the schedule for service for this stream. Now based on the guaranteed rate the ACU determines, the number of frames that arrive in the service interval for stream i assuming that there are $i-1$ streams already undergoing service in the QBSS is given by

$$N_i^{SI} = \left\lceil \frac{SI * g_i^{'}}{L_i} \right\rceil \tag{1.13}$$

Then the ACU calculates the TXOP that is required to service all these MSDUs in a service Interval. This is given by

$$TXOP_i = \frac{N_i^{SI} * L_i}{R_i} + T_i^{overhead} \tag{1.14}$$

Here $T_i^{overhead}$ is the overhead in time. Now the admission control algorithm is given by

$$\frac{TXOP_i}{SI} + \sum_{k=1}^{i-1} \frac{TXOP_k}{SI} \le \frac{T - T_{CP}}{T} \tag{1.15}$$

where T is the beacon interval and T_{CP} is the time reserved for EDCF traffic.

5 Implementation of Admission Control Algorithm

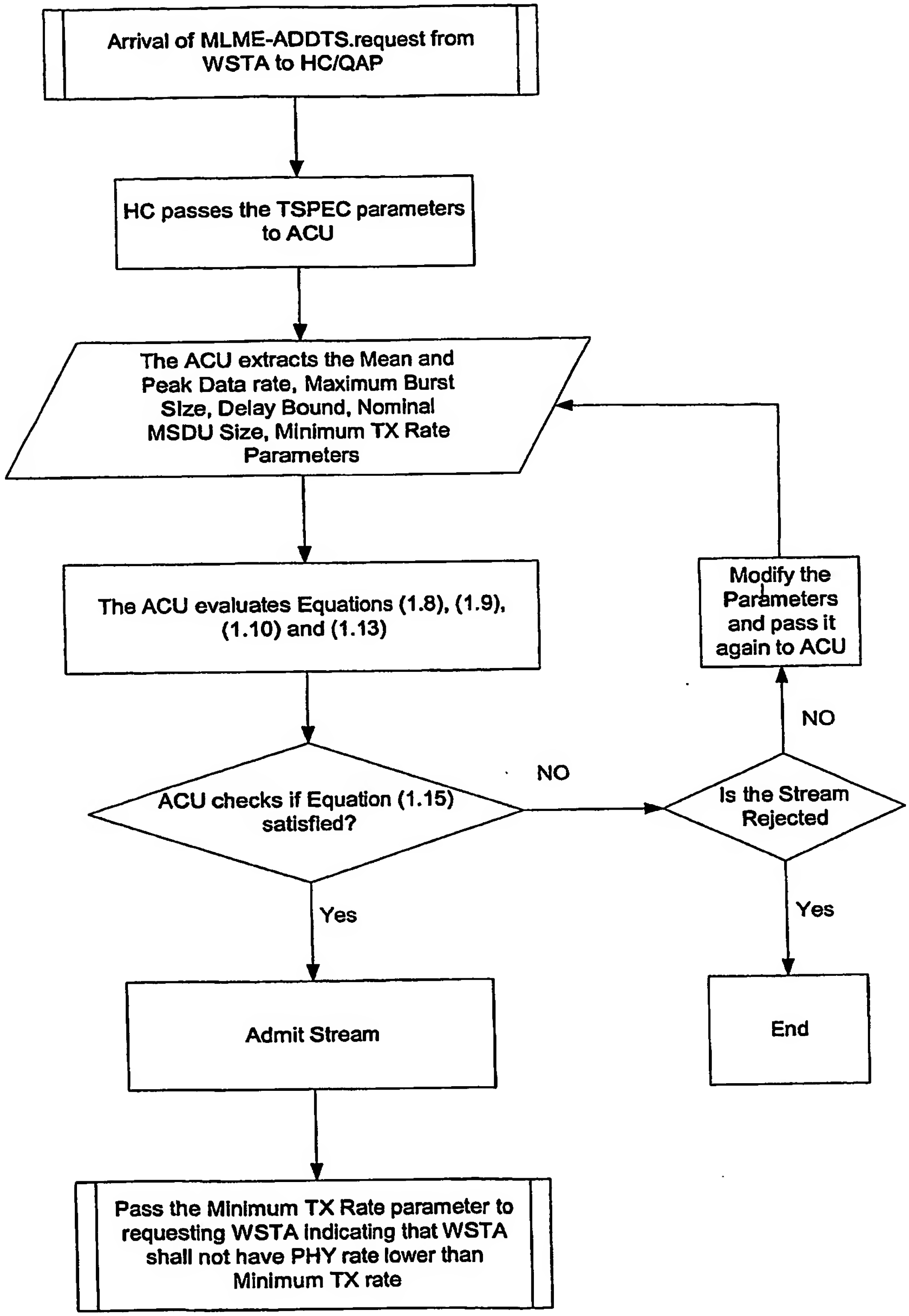
In case of upstream/sidestream or downstream the WSTA makes a request to the HC co-located at the QAP to admit the new or modified TS. The MLME-ADDTS.request primitive is shown in the figure. The TSPEC element as indicated in figure is included in this primitive which is used by the ACU co-located with the HC to determine according to the formulas whether the TS can be admitted or not.

Name	Type	Valid Range	Description
DialogToken	Integer	0-255	Specifies a number unique to the QoS management action primitives and frames used in adding (or modifying) the traffic stream of concern
TrafficSpecification	As defined in frame format	As defined in frame format	Specifies the source address, destination address, TSID, traffic characteristics and QoS requirements of the traffic stream of concern
TrafficClassification (optional)	Opaque object	Beyond the scope of this standard	Specifies the rules by which an MSDU may be classified

Figure 6-Parameters of MLME primitive

The Traffic Classification shown in the figure 6 is used specifically for downstream reservations as it is the WSTA that has to initiate MLME-ADDTS.request primitive. Based on the information from traffic classification element, the WSTA shall generate the TSPEC elements and embed it in the MLME-ADDTS.request primitive. This MLME-ADDTS.request has a response in form of MLME-ADDTS.confirm which indicates to the WSTA whether the connection with the specified TSPEC parameters have been accepted or not. Even in the case of downstream, it is the WSTA that initiates the TSPEC connection.

Now we represent the admission control algorithm in the following flow chart.


Arrival of MLME-ADDTS.request from WSTA to HC/QAP
HC passes the TSPEC parameters to ACU
The ACU extracts the Mean and Peak Data rate, Maximum Burst Size, Delay Bound, Nominal MSDU Size, Minimum TX Rate Parameters
The ACU evaluates Equations (1.8), (1.9), (1.10) and (1.13)
ACU checks if Equation (1.15) satisfied?
NO
Is the Stream Rejected
NO
Modify the Parameters and pass it again to ACU
Yes
Yes
Admit Stream
End
Pass the Minimum TX Rate parameter to requesting WSTA indicating that WSTA shall not have PHY rate lower than Minimum TX rate

5.1 Examples

5.1.1 64 Kbps Voice

Consider a 64kbps voice traffic. Here the Peak and Mean Data rate are the same. Assume that the encoder emits a voice sample every 20 milliseconds. So for every 20 milliseconds we get a voice frame of 1280 bits. This is equivalent to 160 bytes. This voice is transmitted using RTP/UDP/IP layers to the MAC. So the RTP/UDP/IP overheads is 40 bytes. So the frame that arrives at the MAC is 200 bytes. The MAC layer header is another 30 bytes. So the effective arrival rate is 230 bytes/20 milliseconds. Here the Peak Data Rate allocation is the same as the Mean Data Rate allocation. Assume that the PHY Rate is 54Mbps and the Delay Bound parameter is 50 milliseconds. If we admit the stream based on the fact that the service allocated to that stream is near its Delay bound deadline, then one gets to handle 2.5 MSDUs of size 230bytes every 50 milliseconds. For case of simplicity let us take 3 MSDUs per 50 milliseconds. The transmission opportunity for this stream polled near the Delay bound deadline is given by

$$\frac{230\times 8}{54\times 10^{6}}+T_{ack}+3\times SIFS+PIFS+T_{CF-Poll}=(34.1+28+48+25+20)\mu\sec=155.1\mu\sec$$

This TXOP is required every 50 milliseconds for one way call. For 2 way we have 310.2 $\mu\sec$. So the number of calls that can be packed is given by

$$\frac{50\times 10^{-3}}{310.2\times 10^{-6}}=161.2$$

So the maximum number of voice calls that can be admitted is given by 161 assuming no error rates in the channel. This is a simple example and the formulas have not been used as voice traffic is CBR.

5.1.2 VBR Video

Peak Data Rate for DVD quality MPEG 2 Video = 10Mbps
Mean Data Rate = 5Mbps
Maximum Burst Size = 1Mb
Delay requirement = 1 second
Nominal Packet Size = 1500 bytes
Channel Error Rate = 0.05
Service Burstiness = 6Mb Implying that the PHY rate can ossicilate between 54Mbps and 48Mbps only.

The guaranteed rate as per equation 1.8 is 6.14035 Mbps.

Let the SI be 50 milliseconds as before.
Then the number of frames generated during a SI is 26 as per equation 1.13
The TXOP required at 54Mbps, assuming no ACK policy is 6.3milliseconds.

The maximum number of Video calls that can be packed is given by 7.93. Since the number of calls has to be whole number the maximum number of video calls that can be admitted is 7 calls.

6 References

[1] IEEE 802.11e/D3.3, September 2002.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of | Atty. Docket

SAI SHANKAR | US030248

Serial No.:

Filed: CONCURRENTLY

Title: AN EFFICIENT ADMISSION CONTROL ALGORITHM FOR IEEE 802.11e

Commissioner for Patents
Alexandria, VA 22313

APPOINTMENT OF ASSOCIATES

Sir:

The undersigned Attorney of Record hereby revokes all prior appointments (if any) of Associate Attorney(s) or Agent(s) in the above-captioned case and appoints:

STEVEN R. BIREN (Registration No. 26,531)

c/o U.S. PHILIPS CORPORATION, Intellectual Property Department, P.O. BOX 3001, Briarcliff Manor NY 10510, his Associate Attorney(s)/Agent(s) with all the usual powers to prosecute the above-identified application and any division or continuation thereof, to make alterations and amendments therein, and to transact all business in the Patent and Trademark Office connected therewith.

ALL CORRESPONDENCE CONCERNING THIS APPLICATION AND THE LETTERS PATENT WHEN GRANTED SHOULD BE ADDRESSED TO THE UNDERSIGNED ATTORNEY OF RECORD.

Respectfully,

Michael E. Marion, Reg. 32,266
Attorney of Record

S:\BI\MG23BIb0.EC0.DOC